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Nuclear Proliferation using Laser Isotope Separation – Verification Options*

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Two levels of nonproliferation verification exist. Signatories of the basic agreements under the Nuclear Non-proliferation Treaty (NPT) agree to open their nuclear sites to inspection by the IAEA. A more detailed and intrusive level was developed following the determination that Iraq had begun a nuclear weapons development program that was not detected by the original level of verification methods. This level, referred to as 93+2 and detailed in model protocol INFCIRC/540, allows the IAEA to do environmental monitoring of non-declared facilities that are suspected of containing proliferation activity, and possibly further inspections, as well as allowing more detailed inspections of declared sites. 56 countries have signed a Strengthened Safeguards Systems Additional Protocol as of 16 July 2001.

These additional inspections can be done on the instigation of the IAEA itself, or after requests by other parties to the NPT, based on information that they have collected. Since information able to cause suspicion of proliferation could arrive at any country, it is important that countries have procedures in place that will assist them in making decisions related to these inspections. Furthermore, IAEA inspection resources are limited, and therefore care needs to be taken to make best use of these resources.
Most of the nonproliferation verification inspections may be concentrated on establishing that diversion of nuclear materials is not occurring, but some fraction will be related to determining if undeclared sites have nuclear materials production taking place within them. Of these, most suspicions will likely be related to the major existing technologies for uranium enrichment and reprocessing for plutonium extraction, as it would seem most likely that nations attempting proliferation would use tested means of producing nuclear materials. However, as technology continues to advance and new methods of enrichment and reprocessing are developed, inspection-related procedures will need to be adapted to keep up with them.

In order to make 93+2 inspections more useful, a systematic way of finding clues to nuclear proliferation would be useful. Also, to cope with the possible use of newer technology for proliferation, the list of clues might need to be expanded. This paper discusses the development and recognition of such clues. It concentrates on laser isotope separation (LIS) as a new proliferation technology, and uses Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) as an example of LIS that is well known.

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Non-environmental clues to a nuclear proliferation program have been export control violations or attempts, declarations to the IAEA of related work, scientific reports, scientific interaction and exchanges, importation of items not on an export control list but of use for proliferation, and others. These clues may need to be adapted to new technologies such as LIS.

It is important that these clues be known to all parties that might have the opportunity to notice them. A proliferating nation may reduce its scientific interactions for any topics that are related to the chosen technology of proliferation, and only a handful of observers might ever have the opportunity to learn what topics are researched that could raise suspicions. Few scientists might ever visit laboratories that provide leads. Thus, knowledge of these clues should be as widespread as practical, so that no matter who has the opportunity to notice these clues, they will appreciate their significance.

Furthermore, scientific progress in technology that can be adapted to proliferation uses might occur innocently in any nation. It might then be adopted and modified for proliferation use in a nation interested in proliferation. Thus, nations that are not interested in proliferating should be aware of the crossover uses of their scientific and engineering research, so that a database on proliferation technology can be maintained and awareness of this new technology can be brought into the anti-proliferation culture. Thus, if the novel technology is adapted or rediscovered elsewhere in a proliferation-prone nation, notice can be taken.

Of course, a nation near the top rank in scientific capability and with a robust technological sector would have no need to obtain scientific information and engineering know-how to proliferate; the information would already be present. The amount of scientific exchanges between such a nation and the rest of the world are so abundant that no tracking could be done. Covert proliferation by such a nation would not be noticed by the procedures discussed here. Some other method for detecting it would have to be used. The methods here are designed for nations with lesser economic and technological levels.

LIS has been regarded as too difficult a technology for a typical proliferating nation in the middle economic rank (100B$/yr) to utilize[1]. However, as technology advances, this will not remain so. This is partially due to the facilitation that continuing advances in technology often provide. In other words, a technological goal that is barely achievable in one year may become routine decades later, as the supporting technologies useful for it become more well developed. Also the diffusion of technological fine points can make a difference in development time and cost. These are the little details of technology that become refined as a technology is used over and over by different organizations, each of whom does things a little differently or starts with slightly different materials or equipment.

The ability of a nation of middle economic rank to use LIS is also added to by the fact that the requirements for a proliferation facility using LIS are not as strenuous as they are for commercial production of nuclear fuel, economically competitive on the world market. A economically competitive design has to meet different criteria for operating than does one that will be used for proliferation, namely, high reliability and low downtime, low manpower costs, as well as safety limits.

AVLIS is straightforward in concept. It involves sending a beam of neutral atoms across an interaction region, and using narrowband laser photons, tuned to be able to ionize one of the isotopes after absorption of two or three photons, to ionize atoms of the selected isotope only. Then the selected isotope is extracted electrostatically, while the remaining feedstock proceeds across the interaction region to a collection dump. There are a great number of scientific questions that needed to be solved before AVLIS was considered feasible for uranium enrichment. These include finding electronic state transitions of the U235 atom with large enough cross-section, determining the beam parameters to reduce cross-ionization to acceptable levels, and determining what input feedstock contamination would be tolerable. There were also a wide variety of difficult engineering challenges that had to be faced, concerned with the production of the major components of the enrichment machines.

AVLIS has been subjected to extensive research and development in the United States and France for uranium enrichment, and to additional research in India, Russia, Japan, Brazil and other countries for other isotopes. This work has largely solved the scientific and engineering obstacles, although different groups continue to attempt to improve on existing technology for AVLIS. U-AVLIS was also partially brought to a production level in the United States before the program was terminated in 1999 and is heading toward the same result in France, with a mothballing expected in 2003. AVLIS is an enrichment method that is part of the Draft Protocol, and is incorporated as well in Export Control regulations. Thus, this technology has been extensively documented and can therefore be used as a clear example.

The U-AVLIS process has been described as accomplishing enrichment to fuel levels of 3% to 5% in one step[2,3,4] implying an equivalent enrichment coefficient of at least 4.5 to 7.5, about half that theoretically predicted[5], and a large improvement compared to a value of 1.3 for centrifugation. U-AVLIS does not necessarily work identically with all enrichment levels of feedstock, but to obtain a rough estimate of capability, it can be assumed to do so. With this enrichment coefficient, a cascade of four or five stages would be needed to produce highly enriched uranium[6], with about 50 to 120 identical machines in the cascade. If we assume a proliferator wishes to make 100 kg of HEU per year, this corresponds to a throughput per machine of a few kilograms of feedstock a day. This is the scale of the 1984 MARS facility developed in the US U-AVLIS program[7].

The 1984 MARS demonstration facility was a technical tour de force for its time. The two technical areas that dominated the development process were the lasers themselves, and the atomic beam generation by electron gun. That facility used copper vapor lasers to drive dye lasers for the light sources. In the years since that demonstration, laser technology has continued to improve, but also to diffuse broadly into our technical infrastructure. Now, copper vapor lasers are built by high school students for science projects and used in undergraduate laser laboratory experiments; there is also a substantial home hobbyist laser culture that internationally exchanges plans and tips for building them. The same holds true for dye lasers, which are very popular for beginning laser users because of their ease of construction and use. This diffusion of laser knowledge and experimental interest means that expertise about the finer points of laser construction is spreading and will make development of them easier. Furthermore, the capabilities and characteristics of different types of lasers are known much better now than in 1984, and so there would be no need to repeat the screening process to determine types and designs for lasers useful in LIS.

Commercial pressures also add to the advance and diffusion of laser technology. The MARS copper vapor lasers ranged up to about 100 watts[8]. Currently off-the-shelf copper vapor lasers are available with a rated output power of 8 watts, with high reliability. Even less expensive and easier to use lasers may turn out to be useful for U-AVLIS application. In the late 1990's, LLNL developed a solid state replacement for its dye laser oscillator[9]. Free electron lasers (FEL) have also been used for laser isotope separation. Thus, laser technology is not the barrier to LIS that it was twenty years ago.

Electron gun heating continues to develop as well, with guns being used for various industrial purposes, such as melting titanium scrap metal. Medical uses are also being developed. The commercial practice of today may well exceed the laboratory accomplishments of twenty years ago. Electron gun heating is also not the barrier to LIS that it was twenty years ago.

With the diffusion of knowledge that is occurring in these scientific and engineering areas, a nation that sent a cadre of young scientists abroad to research these topics would have the required set of experts in a short period. These experts would have the ability to produce lasers and electron guns from available materials, rather than just the ability to use such devices should they be successfully imported. This means that the export control limitations on this type of component will cease to be a useful indicator of proliferation intentions at some point in time.

An effective response to technology diffusion might be to understand proliferation pathways in detail and then to use these pathways to predict clues.

One tactic a proliferating nation might adopt is to develop everything in secret. This is a slow route as it requires the staff involved to locate answers to all their development problems through their own investigations or research. If this were the case, the only clue would be the training and overseas work experience of scientists and engineers returning to the nation in question. A higher rate of development can be achieved by seeking as much as possible of scientific interchange on related work that can be translated over to a covert program. This interchange, if it is understood, can also lead to clues as to a nation's proliferation intentions.

In order to understand how to interpret if a coherent program exists for nuclear proliferation from training, work experience, or scientific interchange, it is necessary to understand, first, what technological requirements a proliferation program has, and second, how surrogate programs could be used to satisfy these requirements. This means that the path to proliferation that the proliferating nation undertakes has to be understood by those nations in a position to monitor these external indicators. For each feasible enrichment technology, there should be a list of technical achievements that must be accomplished, and what scientific knowledge or engineering know-how is needed for each. When this is available, it will be possible to see how the various parcels of information can be disguised as non-proliferation-related research. This is equivalent to asking how the research and development needed to proceed along a certain proliferation pathway can be decomposed into various apparently innocuous research projects.

This approach is very different from that of export control monitoring. There, each proliferation pathway is examined to find critical items that, by their distinguishability, are indicators of proliferation risk. However, technology continues to seep around these barriers, and more uses are found for some critical items, moving them from items of dual-use to items of easy availability. Worse, the ability to manufacture them indigenously becomes more easily available. In contrast, the approach discussed here attempts to understand a complete map of proliferation and the technologies involved, and to check to see how many of the items on the map are being pursued in the nation that is suspected of proliferating.

To return to U-AVLIS as an example, at the level of least detail, requirements include high power tunable lasers in the visible, systems to measure their output pulses, wavelengths, and other characteristics, optical systems capable of producing wide uniform beams, electron guns able to vaporize a certain amount of uranium, beam control fixtures, and coatings that resist liquid uranium metal. As we have considered that these components will be made, not bought, the next level or two of detail is needed. For a high-power laser, special power supplies, purification of the lasing media, tube-cooling devices, heat-resistant glass surfaces, and laser pumping systems are needed. For measurement systems, very fast circuitry, accurate visible wavelength spectrometers, and power measuring devices would be needed. Similar lists can be developed for each of the other components. An understanding of the technologies is necessary to see through any disguised knowledge retrieval projects. For example, power supplies suitable for lasers might have related uses, and unless this type of technology equivalence were known, the indication that the subject was under investigation might be missed.

Thus, if the U-AVLIS proliferation pathway was being followed, a proliferating nation that did not already have technical capability and expertise in these areas would have to obtain it, and signs of this in a plethora of these key research and development areas would be a clue that the suspect nation was following the expected pathway to proliferation. The same is true for any other pathway. Once a suspect proliferation pathway is found in a suspect nation, the remaining task for the suspicious nation or organization is to understand when in the pathway a covert facility would be produced, and what its size and characteristics would be.

Since the suspect nation is proceeding along a proliferation pathway based on technological expertise obtained by a few recognizable individuals, their transfer, reassignment or disappearance would be a clue that the covert facility was ready to use their specialties. Location of these specialists, via any means of finding or tracking persons, would serve to provide the location for a requested 93+2 search.

Imports at a lower level that those caught in the export control sieve might also be clues to high-technology proliferation, if these proliferation pathways were understood in enough detail to pinpoint needed items. If the nation makes a policy choice to go covert before doing any work requiring disclosure to the IAEA, no clues will come from this source, but if they opt to go covert at a later stages, these declarations might provide one of the best sources of information to help discriminate which proliferation pathway or pathways might have been chosen.

In summary, this paper argues that high-technology outflanking of export controls might be occurring in nations with moderate-size economies during the first decades of the twenty-first century. This is made possible by the continued advance and diffusion of technologies usable for components of a method for obtaining nuclear materials. This outflanking will eliminate one source of clues that might be used to focus on-ground investigative efforts under the IAEA 93+2 protocols. An alternate, though more labor intensive, source of clues would be monitoring training, work experience and scientific interchange of nationals of a possible proliferating nation. To make this source useful, proliferation methods must be understood in greater technological detail, and databases compiled on the occurrence of technology components that present the research and engineering challenges to a mid-sized nation attempting proliferation. These nationals' activities can then be used to provide indications of when and where on-ground investigations might be useful. This is done already, but it needs to be done more systematically as technology continues to diffuse. It needs to be done internationally, as technology advances and refinements occur internationally, and also because the opportunity to observe or learn of activity contributing to a proliferation activity might be rare and restricted to only a few scientists or technologists.

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